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EVALUATION OF STAPLE POLYESTER/ MICROFIBROUS POLYOLEFIN BLENDED BATTING AS A POTENTIAL THERMAL INSULATING MATERIAL FOR CLOTHING

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The use of a new batting (composed of a blend of 43% polyester staple fibers and 57% polyolefin microfibers without binders) in lieu of the standard batting (composed of 100% staple polyester fiber with 10% resin binder) within U.S. Army jacket and trouser liners was investigated.

Initial laboratory characterization indicated that the new batting afforded thermal insulative protection equal to an equivalent weight of uncompressed standard polyester batting

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but half the thickness (bulk). However, this relationship did **not** translate into actual liner composite testing. The addition of cover fabrics and quilting changed the proportion and rate of radiative, convective, and conductive heat energy transfer thru these assemblies.

sq.

Thus, at equivalent areal density (i.e., oz/yd^2), the new material in **unquilted** panel form exhibited thermal resistance values ranging from 15 to 45% greater than that of the standard polyester batting in **quilted** panel form. Coincidently, the thickness of the **unquilted** new batting and **quilted** standard batting liner panels were equivalent.

With laundering, the decrease in the thermal resistance values of the new batting composites coupled with a slight increase in that of the standard resulted in a basic equivalence of thermal insulative protection. Furthermore, surface area shrinkage ranged from 8 to 13% with the new batting composites versus 4% for the standard.

It is concluded that this new batting is not a suitable substitute filling media within US Army field jacket and trouser liners.

SUMMARY

A new thermal insulating material was investigated to determine its potential as a substitute for the standard *resin-stabilized polyester batting now being used in the* U.S. Army's field jacket and trouser liners. The new nonwoven batting is a blend of 43% polyester staple fibers and 57% polyolefin microfibers without binders, whereas the standard material is 100% staple polyester fibers with a nominal 10% resin binder.

Evaluations included:

a. Guarded hot plate testing of single and multiple layers of both the new and standard filling materials in the uncompressed state.

b. Rapid "K" thermal conductivity testing of these materials under increasing static compressive loads.

c. Thermal resistance and dimensional stability measurements of prototype and standard liner composites before and after military laundering.

Testing showed that the new batting affords thermal insulative protection equal to an equivalent weight of uncompressed standard polyester batt but half the thickness. However, in the actual design of a thermal insulating composite, the following considerations were found to be important:

a. Cover fabrics have a varying positive effect on the total thermal resistance of any specific batting composite. The total result is a function of batting bulk density, thickness, and opacity to infrared transmission. The addition of lightweight nylon ripstop cover fabric to the comparatively translucent standard polyester batt resulted in a 49% increase in thermal resistance. This result is indicative of a significant reduction in convective and radiative heat losses. The thermal resistance of the more opaque, denser experimental batting increased by only 2% with the same cover fabric.

b. Without quilting, dimensional stability and thermal resistance properties of the standard polyester batting could not be maintained upon laundering. However, quilting of filling materials decreases the thickness and thermal resistance value.

c. The thermal resistance reduction upon application of increasing compressive static loading is not proportional to batting thickness loss. Upon quilting, a 52% loss of the standard polyester batting composite thickness was accompanied by a 35% loss in thermal resistance. In contrast, quilting of the new batting composite samples resulted in thickness reductions of 19 and 25% and corresponding thermal resistance losses of 30 and 33%, respectively. The increase in bulk density and decrease in thickness of all composite samples upon quilting caused a change in the proportion and rate of radiative, convective, and conductive heat energy transfer.

Liner composite evaluations revealed:

a. Although the new batting composites of approximate equivalent weight in unquilted form or equivalent thickness in quilted form do exhibit initially superior thermal insulative

protection, upon laundering all new batting composites sustained losses in loft, thermal resistance and surface area (shrinkage). In contrast, the standard quilted polyester batting composite exhibited a slight increase in loft and thermal resistance with minimal loss in surface area with laundering.

b. The use of a nonwoven polyester scrim on both sides of an unquilted new batting or quilting of a heavier weight new batting provided minimal composite surface area shrinkage and comparable thermal insulative protection with laundering. Both, however, are of greater bulk and weight than the standard quilted polyester composite.

It is concluded that this new batting is not a suitable substitute for the standard resin-stabilized polyester batting within U.S. Army field jacket and trouser liners.

However, in view of this new batting's superior thermal insulative performance characteristics prior to laundering, a study to determine its comparative performance in unlaundered end-items applications is warranted.

ACKNOWLEDGEMENT

The author wishes to thank Mr. Frank Calabrese, Clothing, Equipment & Materials Engineering Laboratory, for his cooperation and assistance in the fabrication of liner composite panels and in expediting acquisition of quilted batting materials.

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I. INTRODUCTION

The U.S. soldier operating in a cold environment requires clothing and personal equipment which will protect him from the elements. One of the most essential features of these items is their ability to provide sufficient warmth for the individual at low temperatures. Research on insulating materials has been a continuing program at NARADCOM for the past several years. The objectives of this effort have been aimed at increasing the insulative capabilities of the materials and decreasing their bulk and/or weight.

The military applications of thermal insulation vary widely and include clothing, handwear, footwear, sleeping gear, and tentage. Each application has specific requirements which demand that the insulative material possess certain physical characteristics, such as, strength, thickness, resiliency, launderability, compressibility, rigidity, etc. Consequently, a material's inability to perform satisfactorily in one particular use does not necessarily mean that it would not be the ideal material in some other instance. Therefore, it is often necessary to resort to the fabrication and test of experimental prototypes before a decision can be reached on the acceptability of a material.

Recently, much attention has focused on a new commercial product which has made its way into the high performance insulative skiwear market. This material, which is composed of polyester staple fibers and polyolefin microfibers in a 43/57 blend, appeared to be an extremely promising candidate to replace the resin-stabilized polyester batting now employed as the filling material in the liners of the Army standard field jacket and trousers. This report details the results of a laboratory investigation of this material as a potential substitute for the standard batting in these items.

II. OBJECTIVE

The overall objective of this effort was to determine the suitability of a new insulating material, composed of 43/57 blend of polyester staple fibers and polyolefin microfibers, as a substitute for the standard resin-stabilized polyester batting in liners for the Army standard field jacket and trousers. Intermediate objectives were to characterize the new material's thermal insulative performance over the entire range of its commercially available areal densities and to compare this performance with the standard material at both equivalent weight (areal density) and thickness.

III. MATERIALS

The following materials were employed in this study:

1. Standard Resin-Stabilized Polyester Batting

4.0 oz/yd^2* conforming to MIL–B–41826,[1] Type IV, fiber denier 5–6.

[1] Military Specification MIL–B–41826, Batting, Synthetic Fibers: Polyester, (Quilted and Unquilted) (27 June 1979)

*U.S. Customary units are commonly used throughout the synthetic batting industry.

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2. Experimental Batting Material

Nonwoven batting composed of 43% polyester staple fibers (12.6 to 14.1 denier) and 57% polyolefin microfibers (0.001 to 0.340 denier) without binder in the following densities:

Nominal Areal Density oz/yd^2	Nominal Bulk Density lb/ft^3
2.95	0.68
4.4	0.76
5.9	0.82

3. Ripstop Nylon

1.1 oz/yd^2 fabric conforming to MIL–C–43637.[2]

4. Scrim

Nonwoven polyester scrim, 0.8 oz/yd^2.

IV. TEST METHODOLOGY

The thermal performance envelope for both the standard and experimental materials in single and multiple layers was determined in the uncompressed condition on the Guarded Hot Plate to (1) define the thermal resistance (insulating value) as a function of thickness and areal density and (2) establish the change in performance with increasing bulk density. The thermal resistance (clo value) was measured without compressive loading in accordance with ASTM D1518–77, Standard Test Method for Thermal Transmittance of Textile Materials between Guarded Hot-Plate and Cool Atmosphere.[3] A Dynatech R/D Company Guarded Hot Plate was used in this phase of the study.

The thermal insulative performance of these materials under compression was determined using the Rapid "K" Thermal Conductivity Instrument. Individual curves illustrating thermal resistance and thickness as a function of static compressive loading were generated for each

[2] Military Specification MIL–C–43637, Cloth, Ripstop, Nylon: For Poncho Liners (5 September 1974)

[3] ASTM D1518–77 – Standard Test Method for Thermal Transmittance of Textile Materials between Guarded Hot-Plate and Cool Atmosphere (1977)

material. Measurements under various static compressive loads were made in accordance with ASTM C518–76, Standard Test Method for Steady-State Thermal Transmission Properties by Means of the Heat Flow Meter.[4] A Dynatech R/D Company, Model Rapid K, Thermal Conductivity Instrument was used for these evaluations.

The nine candidate liner composites shown in Table 1 were prepared as follows:

(1) Unquilted prototypes (samples C, E, F) of approximate equivalent areal density as the standard quilted liner composite (sample B – 6.2 oz/yd^2).

(2) Quilted prototype (sample D) of approximate equivalent areal density as the standard quilted liner composite (sample B – 6.2 oz/yd^2).

(3) Quilted prototype (sample H) of approximate equivalent thickness as the standard quilted liner composite (sample B – 0.55 in.).

(4) Unquilted prototypes (samples G, I) of approximate equivalent thickness as the unquilted standard liner composite (sample A – 1.14 in.).

The thermal resistance of each structure was measured using the Guarded Hot plate test method cited above.

The composites were then subjected to three cycles of military laundering and their resultant thermal resistance determined. Laundering was accomplished in accordance with Method 5556 – cotton laundering – of Federal Test Method Standard 191.[5] Wash temperature was 140°F and drying temperature was 135°F.

Thicknesses were determined with a Standard Certain-Teed Corporation Measure-Matic Unit. Do-ALL precision gage blocks were used to calibrate at each level of measurement from 0.15 to 4.50 inches.

A Hewlett Packard (H/P) Model 3052A Data Acquisition System (including H/P 3455A Digital Voltmeter, H/P 3495A Scanner and H/P 9825A Programmable Calculator) was used to perform real time on-line collection and analysis of the data generated.

[4] ASTM C518–76, Standard Test Method for Steady-State Thermal Transmission Properties by Means of the Heat Flow Meter (1976).

[5] Method 5556, Mobile Laundry Evaluation for Textile Materials of Federal Test Method Standard No. 191A, Federal Standard for Textile Test Methods (20 July 1978)

TABLE 1. CANDIDATE LINER COMPOSITES

Sample Designa-tion	Sample Description	Nominal Filling Material Areal Density Oz/Yd^2	Nominal Composite Areal Density Oz/Yd^2	Nominal Composite Thickness In
A	Unquilted Nylon/Polyester/ Nylon	4.0	6.2	1.14
B*	Quilted Nylon/Polyester/ Nylon	4.0	6.2	0.55
C	Unquilted Nylon/Experimental Batting/Nylon	4.4	6.6	0.52
D	Quilted Nylon/Experimental Batting/Nylon	4.4	6.6	0.42
E	Unquilted Nylon/Scrim/ Experimental Batting/Nylon	4.4	7.4	0.54
F	Unquilted Nylon/Scrim/ Experimental Batting/ Scrim/Nylon	4.4	8.2	0.57
G	Unquilted Nylon/ Experimental Batting/ Experimental Batting/ Nylon	8.8	11.0	0.92
H	Quilted Nylon/Experimental Batting/Experimental Batting/Nylon	8.8	11.0	0.69
I	Unquilted Nylon/Scrim/ Experimental Batting/ Experimental Batting/ Scrim/Nylon	8.8	12.8	1.02

*This sample represents the material and construction of the Army's standard field jacket and trouser liner.

NOTE: Above composite samples were fabricated in a rectangular configuration with overedge safety stitching to secure components together.

V. RESULTS AND DISCUSSION

1. Material Insulation Properties

a. Without Compression

Figures 1 and 2 illustrate the thermal performance curves of the experimental material, whereas Figures 3 and 4 present similar data for the standard polyester batting. These figures show that the relationship between thermal resistance and thickness or areal density of low density fibrous thermal insulations, unlike high density material, is not linear. For example, as shown in Figure 1 at 1-inch thickness, the thermal resistance value is 4 clo. If a 4-clo/inch constant were assumed, a thermal resistance value of 8 clo would be projected for a 2-inch thickness of this material. However, 7.2 clo was the actual measured value. This nonlinearity of thermal normalization parameters is due to the so-called "Thickness Effect".[6] Briefly defined, in evaluation of low density (below 1 lb/ft^3) fibrous insulating materials, as the test sample thickness is increased, the calculated thermal resistance per unit thickness decreases. This is attributed to the significantly greater proportion of heat energy transfer by radiation through these low density materials compared to dense materials.

In a purely radiation heat transfer situation (for example, two parallel plates at different steady-state temperatures within a vacuum environment), the total rate of heat energy transfer remains constant regardless of the distance between the radiating surfaces. Conversely, in a purely conduction heat transfer situation (for example, a dense insulating material with parallel surfaces held at different steady-state temperatures), the total rate of heat energy transfer decreases linearly with an increase in sample thickness. Thus, in low density fibrous thermal insulation evaluation where both radiation and conduction transfer occur simultaneously, the total heat flux decreases with increasing thickness, but not proportionately. Consequently, clo/in or $clo/oz/yd^2$ values obtained from thin specimen testing tend to overestimate the effectiveness of the insulation at greater thicknesses. Direct thermal resistance determination at full "use" thickness is, therefore, required.

Figures 3 and 4 also show that as the bulk density of the standard material is increased, its thermal insulative performance on a thickness basis is improved, but its performance on a weight (areal density) basis is degraded. With the experimental material (Figures 1 and 2), the performance on a weight basis behaved similarly: however, there was no significant change in thermal performance on a thickness basis.

Examination of the comparative performance curves (Figures 5 and 6) reveals that at equivalent batting areal density, the experimental material is approximately one half the thickness of the standard and provides equal thermal protection. This suggests that garments

[6] Marion Hollingsworth Jr., "Experimental Determination of the Thickness Effect in Fibrous Insulations", Thermal Insulation Conference, Tampa, Florida (October 1978)

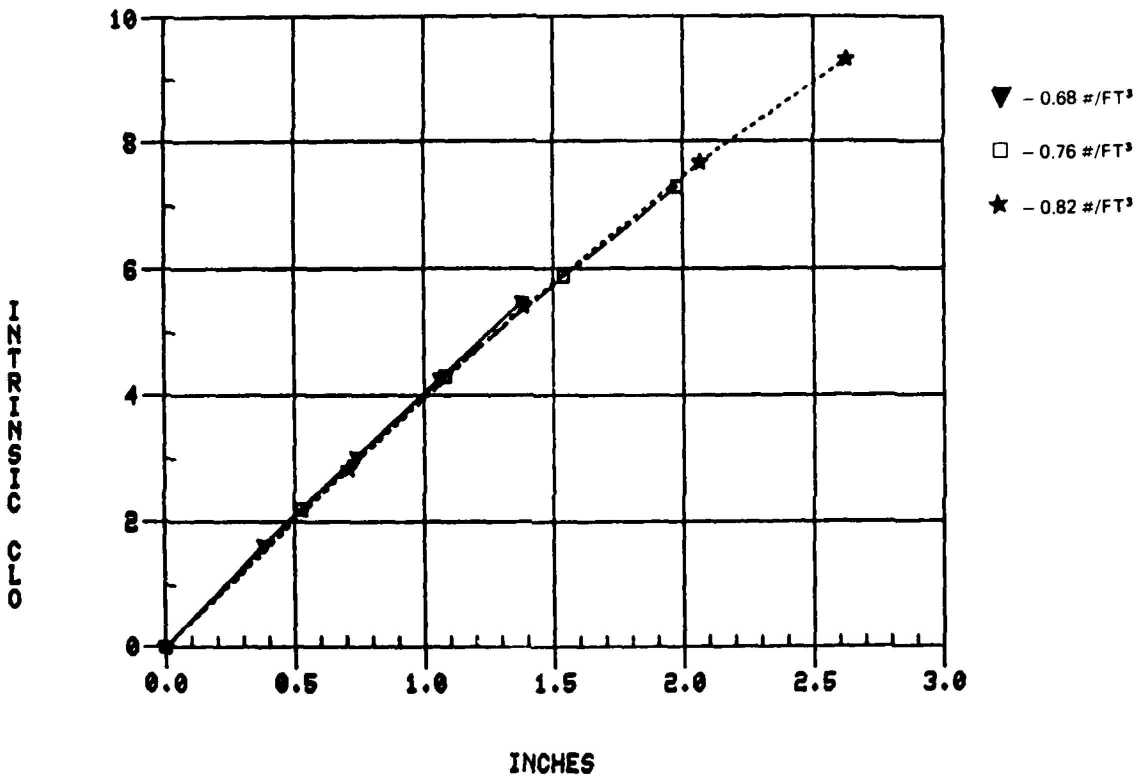

Figure 1. Experimental Batting –
Thermal Resistance vs. Thickness

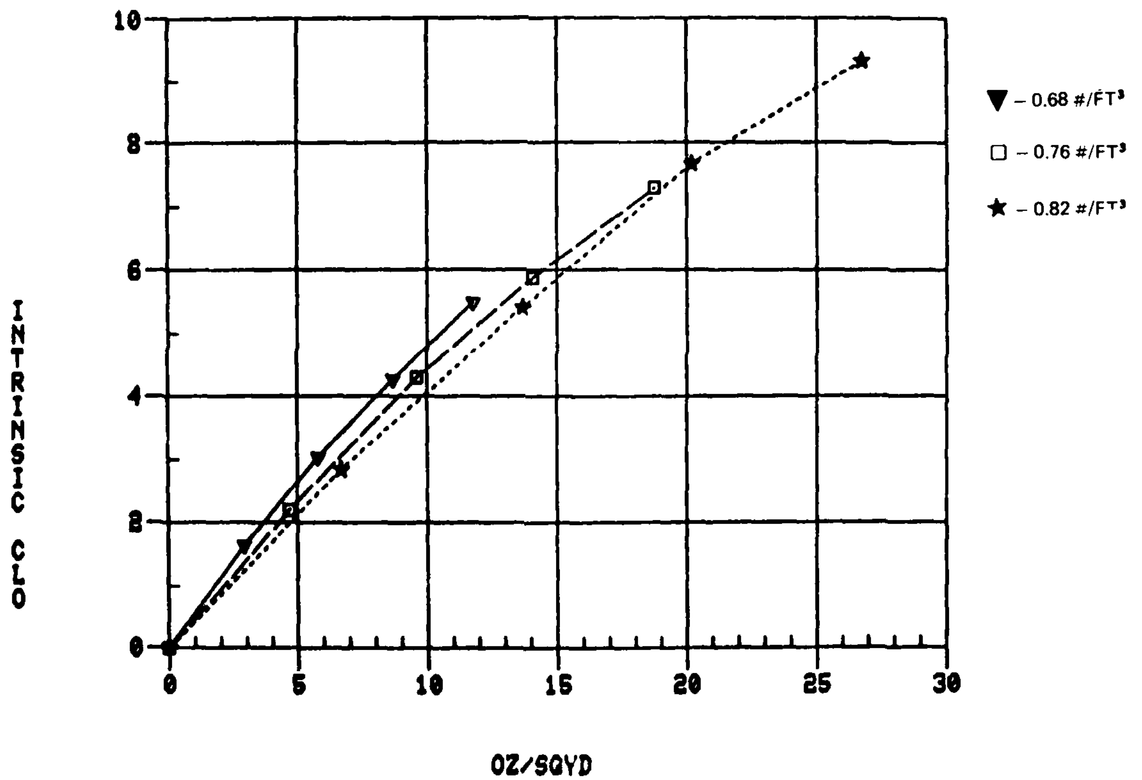

Figure 2. Experimental Batting –
Thermal Resistance vs. Areal Density

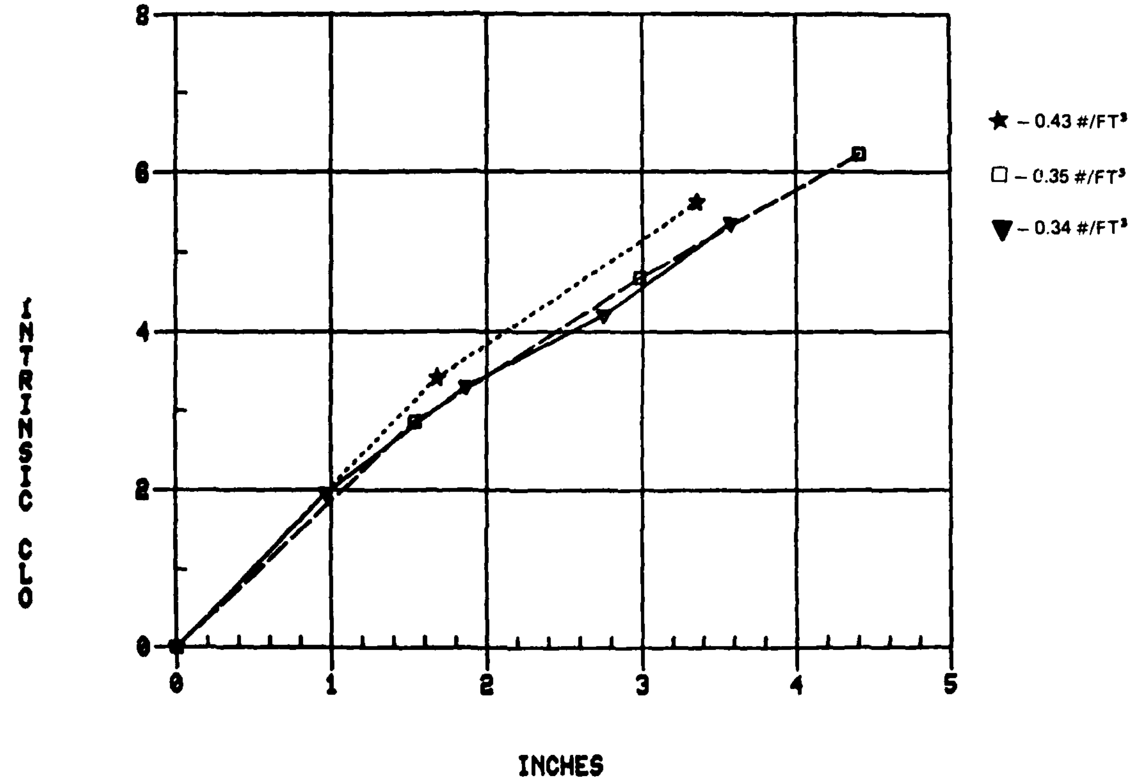

Figure 3. Standard Batting – Thermal Resistance vs. Thickness

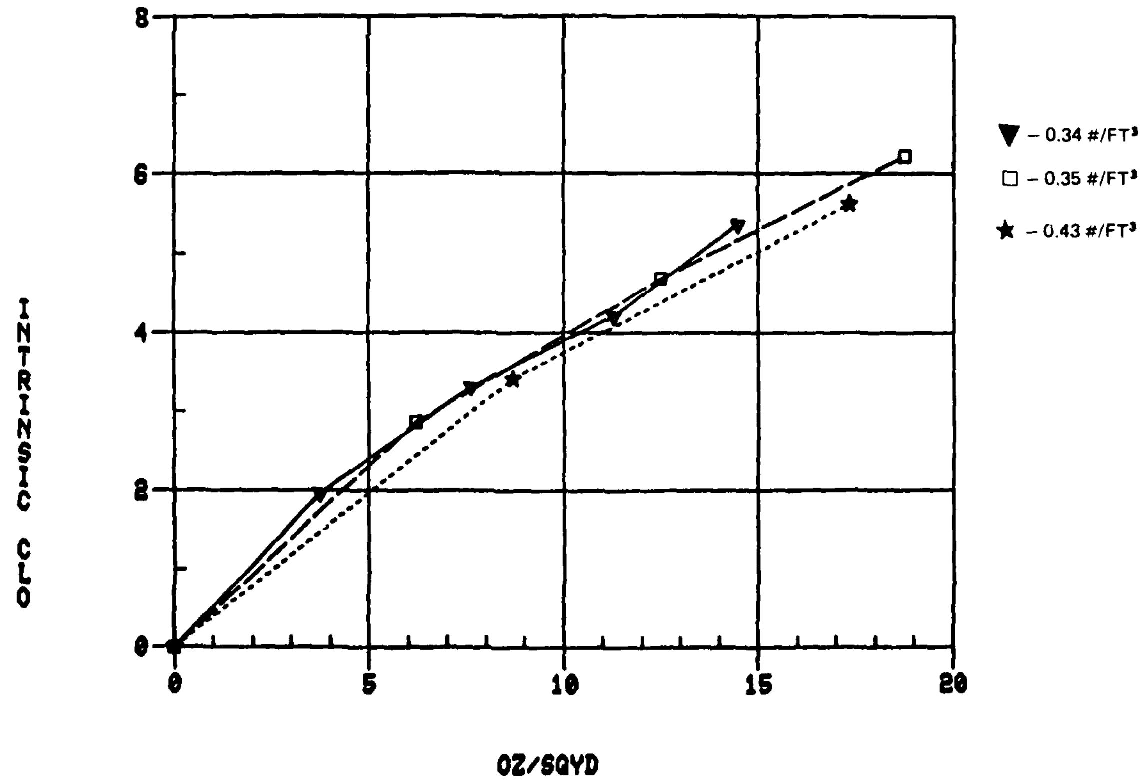

Figure 4. Standard Batting – Thermal Resistance vs. Areal Density

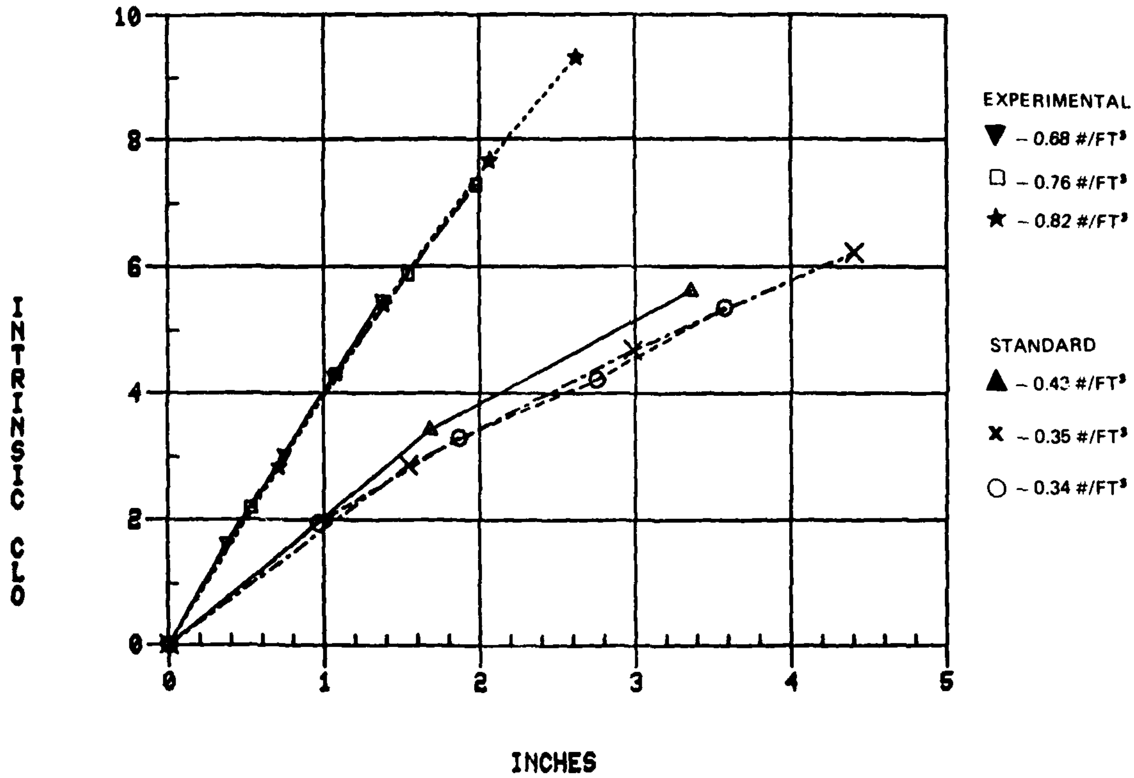

Figure 5. Experimental & Standard Batting – Thermal Resistance vs. Thickness

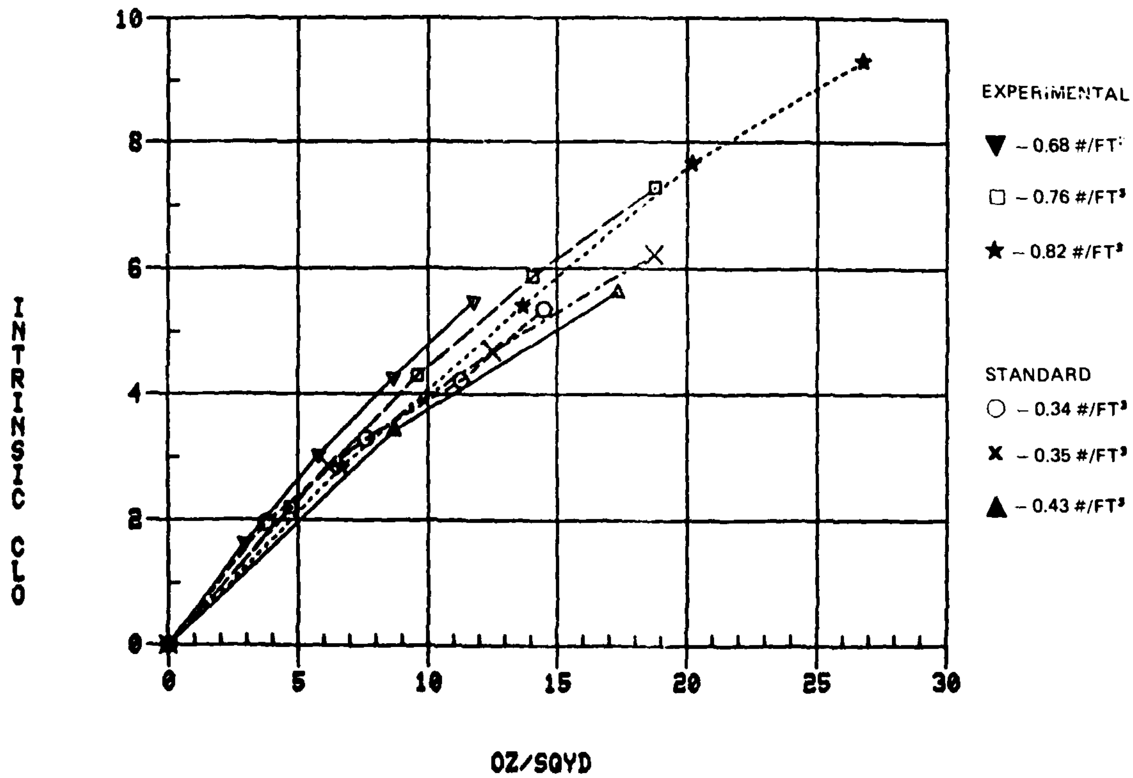

Figure 6. Experimental & Standard Batting – Thermal Resistance vs. Areal Density

filled with an equivalent weight of the experimental material would be of the same warmth and half the bulk of the polyester filled garments, and would thereby enhance the individual soldier's mobility.

b. Under Compression

Figures 7 and 8 illustrate the drastic reduction of loft (thickness) of both insulative materials under very light compressive loads and the resulting decrease in insulation value. Figure 9 shows the non-linear relationship between insulation value and compressed thickness. Note that the polyester batt displays less loss in thermal resistance with a given reduction in thickness. These curves are indicative of how the thermal insulative performance of garments with these filling materials degrades when subjected to compressive loading (for example, a soldier lying in prone position in a combat situation would apply compressive loads to his garments). In addition, this information is predictive of the loss of thermal performance in quilting filling materials within garments.

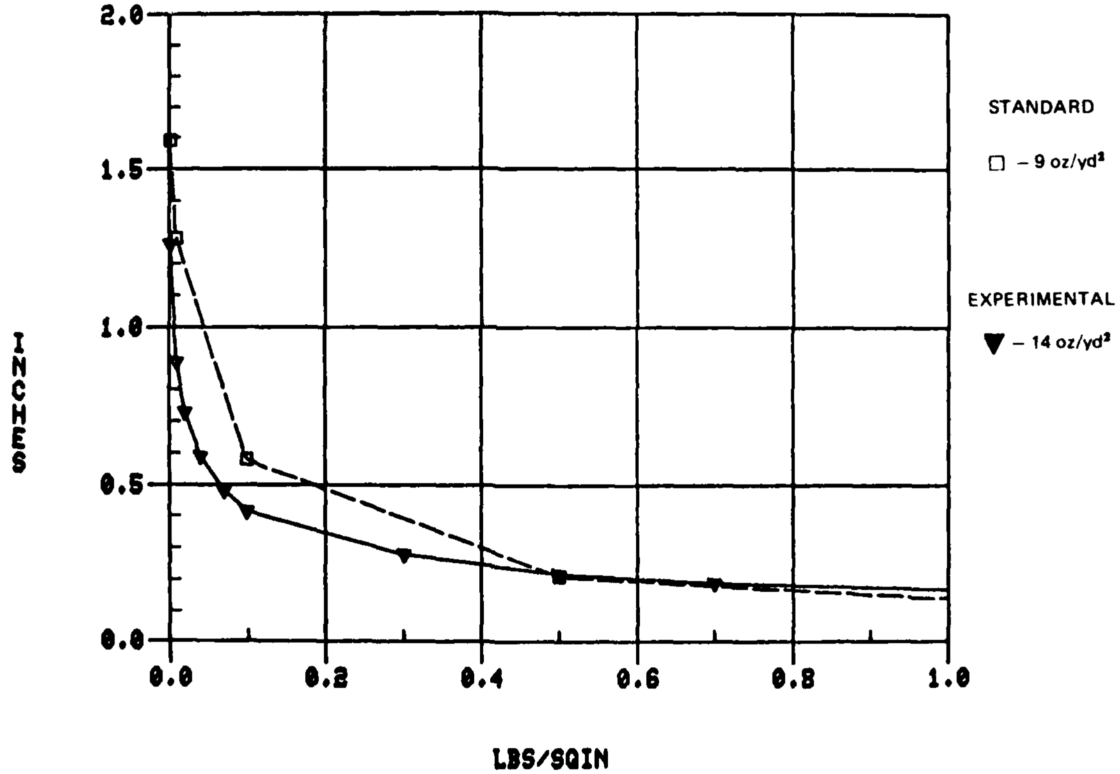

Figure 7. Experimental & Standard Batting – Thickness vs. Static Loading

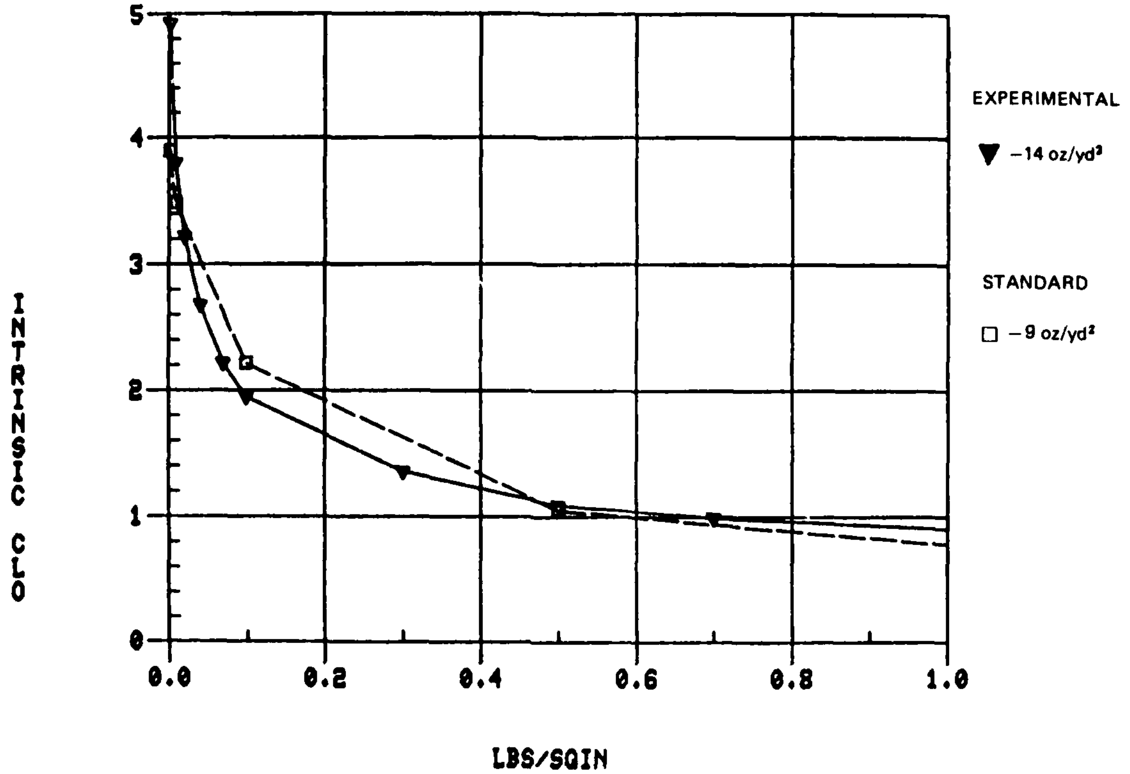

Figure 8. Experimental & Standard Batting – Thermal Resistance vs. Static Loading

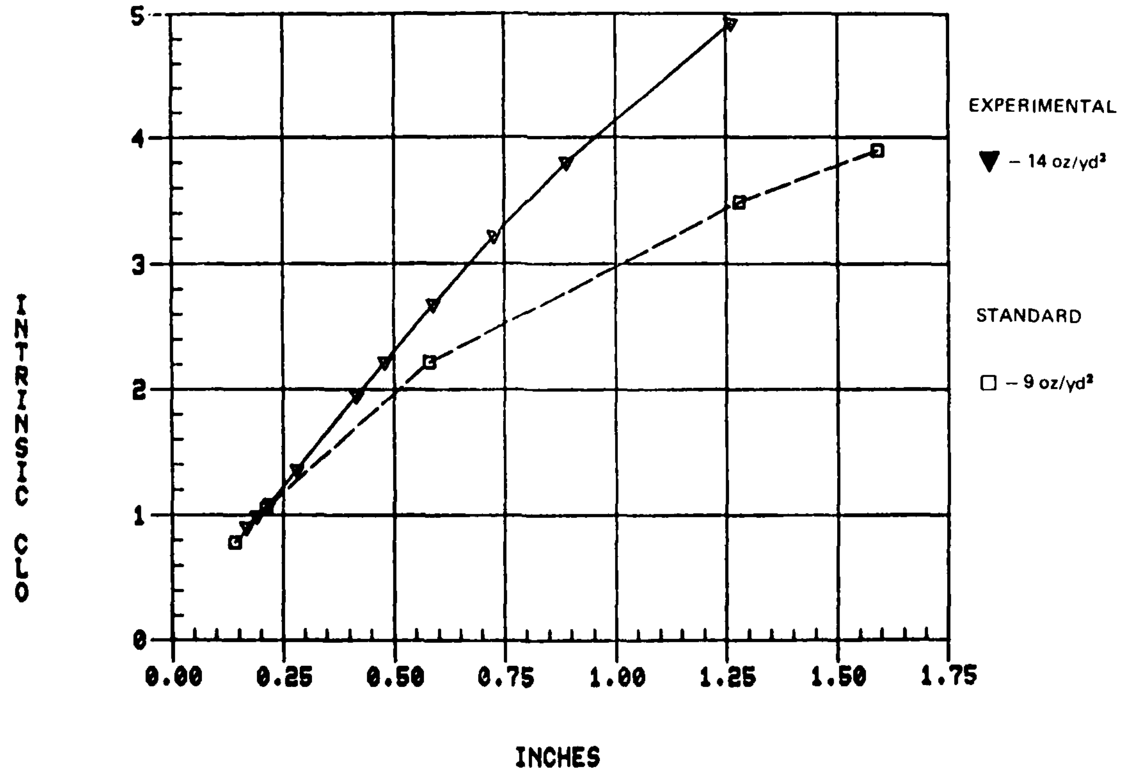

Figure 9. Experimental & Standard Batting – Thermal Resistance vs. Compressed Thickness

2. *Composite Insulation Properties*

a. Estimated vs. Measured Liner Composite Thermal Resistance Values (R Values)

The design of thermal insulative material systems requires both the definition of the thermal insulative protection levels required to meet specified objectives and the identification of alternative composite structures that meet those objectives. Standard R value estimation techniques were, therefore, applied to predict the composite thermal insulative performance of the various test structures.

The estimate of each candidate liner's thermal resistance (R value) is listed in Table 2. Estimates for the unquilted composites (A, C, E, F, G, I) were determined by summing the individual component material's R values [$R_{Fabric} + R_{Batting} + R_{Fabric}$]. The individual R values for the 1.1 oz/yd^2 nylon ripstop and the 0.8 oz/yd^2 polyester scrim are 0.04 and 0.20 clo, respectively.

Estimates of the quilted composites R values were determined by:

(1) Calculating the percent loss of loft (thickness) between the unquilted and quilted composite.

(2) Estimating from the compression curves of Figure 9 the expected percent loss of insulating value for the calculated percent loss in loft.

(3) Calculating the product of the percent loss of insulation value and

(a) the measured R value of unquilted composite, or

(b) the estimated R value of unquilted composite.

(4) Subtracting (3)(a) product from the measured R value of unquilted composite.

(5) Subtracting (3)(b) product from the estimated R value of unquilted composite.

The following observations can be made from these estimations:

(1) The estimated R values for unquilted experimental batting composites C, E, F, G, and I correlate fairly well with actual measured R values. The only apparent disagreement occurs in the results of sample A (unquilted nylon ripstop/polyester batting/nylon ripstop). Here, the estimated value is 30.2% less than the measured value. This discrepancy is attributed to the significant reduction in radiative and convective heat energy loss caused by addition of nylon ripstop cover fabrics to the very translucent low density polyester batt. In contrast, sample C where the appreciably more opaque and more dense experimental batting is used, the estimated value is slightly greater (1.3%) than that measured.

(2) Two estimated R values for quilted samples B, D, and H are listed in Table 2. These values were determined using the actual measured R value in one case and the estimated

TABLE 2. PROJECTED AND ACTUAL THERMAL RESISTANCE VALUES OF LINER COMPOSITES

Sample Designa-tion	Measured R Value (CLO)	Estimated R Value (CLO)	% Variation From Measured R Value
A	2.98	2.08	- 30.2
B	1.95	1.96*/1.37	+ 0.5/- 29.7
C	2.25	2.28	+ 1.3
D	1.57	1.91*/1.93	+21.7/+ 22.9
E	2.50	2.48	- 0.8
F	2.83	2.68	- 5.3
G	3.88	4.39	+ 13.1
H	2.58	3.12*/3.52	+20.9/+ 36.4
I	4.70	4.79	+ 1.9

*From measured unquilted composite R value.

R value for the corresponding unquilted composite in the other. The correlation between the estimated R value of each quilted composite based upon calculations using the measured R value of the corresponding unquilted composite was better than that based upon calculations using the estimated R value.

b. Effect of Quilting

Sample B, fabricated by quilting sample A liner composite material in the standard dumbbell stitching pattern, showed a significant decrease in both thickness and insulation value. However, although the thickness of this polyester liner composite decreased by 52%, the corresponding thermal resistance value decreased by only 35%. In contrast, the quilted experimental batting, samples D and H, showed reductions of 19 and 25% in loft and R value losses of 30 and 33%, respectively, from unquilted samples C and G. This is brought about by the increase in bulk density and the decrease in thickness of the samples upon quilting and the resultant change in the proportion and rate of radiative, convective, and conductive heat energy transfer.

c. Effect of Laundering

Tables 3 and 4 show the effect of laundering upon the thermal insulative performance and dimensional stability of standard and candidate liner composites. Examination of these data reveals that quilting of the standard resin-stabilized polyester batting liner material (Sample A to B) is required to maintain dimensional stability and thermal insulative performance **with laundering**. However, the 35% loss in R value first encountered by quilting is not made worse with laundering.

The experimental batting C and G liners, on the other hand, not only suffered R value losses of 30 and 33%, respectively, upon quilting (as shown by samples D and H), but further losses of 12.7 and 15.1% with laundering. Additionally, the R value losses upon laundering of the unquilted experimental batting liners (samples C, E, F, G, and I) ranged from 14.6 to 28.5%. Surface area shrinkage of all the experimental liner composites ranged from 7.5 to 15.4% as opposed to 4.2% for the standard quilted polyester liner. These adverse laundering effects cannot be attributed to softening of the polyolefin fiber component as wash water and drying air temperatures of 140 and 135°F, respectively, are well below the material's melting point (302°F).

d. Effect of Scrim

A nonwoven polyester scrim material was found to be an effective means of keeping the highly static experimental batting layers apart and facilitated separation and assembly of the material. As shown in Tables 3 and 4, the scrim improves the dimensional stability of the unquilted experimental batting liner composites upon laundering; however, it has a deleterious effect on thermal performance. Examination of the laundered composite showed that the microfibers become entangled in the scrim upon laundering, and thus reduce the overall sample thickness and corresponding thermal resistance values.

TABLE 3. EFFECT OF LAUNDERING UPON THERMAL INSULATIVE PERFORMANCE OF CANDIDATE LINER COMPOSITES

Sample Designation	R Value Before Laundering (CLO)	R Value After Laundering (CLO)	% Gain or Loss
A	2.98	*	*
B	1.95	2.03	+ 4.1
C	2.25	1.92	-14.6
D	1.57	1.37	-12.7
E	2.50	1.81	-27.6
F	2.83	2.07	-26.9
G	3.88	2.92	-24.7
H	2.58	2.19	-15.1
I	4.70	3.36	-28.5

*Unable to perform due to excessive shrinkage upon laundering.

TABLE 4.

EFFECT OF LAUNDERING UPON THE DIMENSIONAL STABILITY OF CANDIDATE LINER COMPOSITES

Sample Designation	Thickness* Before Launderings (Inches)	Thickness* After Launderings (Inches)	Size Before Laundering (In x In)	Size After Laundering (In x In)	Surface Area Before Laundering (In^2)	Surface Area After Laundering (In^2)	% Decrease in Surface Area
A	1.14	**	23.6 x 23.6	**	557.0	**	**
B	0.55	0.57	23.25 x 24	22.75 x 23.5	558.0	534.6	- 4.2
C	0.52	0.49	24.375 x 24.6	22.625 x 22.95	599.6	519.2	-13.4
D	0.42	0.40	23 x 23	22 x 22.25	529.0	489.5	- 7.5
E	0.54	0.45	25 x 25	23 x 24	625.0	552.0	-11.7
F	0.57	0.47	23.625 x 23.75	22.5 x 23	561.1	517.5	- 7.8
G	0.92	0.73	23.7 x 25.7	22.7 x 22.7	609.1	515.3	-15.4
H	0.69	0.60	23.5 x 23.6	22.5 x 22.75	554.6	511.9	- 7.7
I	1.02	0.85	23 x 23.75	22.25 x 22.25	546.3	495.1	- 9.4

*Thickness Measurements were made at "touch" pressure (0.002 psi)

**Unable to perform due to excessive shrinkage upon laundering.

e. **High Areal Density Composites**

Experimental batting liner composites G, H, and I showed thermal insulation properties which were superior to the standard after laundering. However, their weight is twice that of the standard sample B. Consequently, this would impose a mobility penalty on a soldier when used as a garment liner.

The insulation properties, bulk and shrinkage of unquilted experimental batting sample F compare favorably with the quilted standard, sample B. However, its areal density is approximately 30% greater (8.2 vs. 6.2 oz/yd^2) and its projected cost is 35% higher ($2.90/yd^2 vs. $2.15/yd^2 (quilted)).

VI. CONCLUSIONS

The experimental batting material is not considered a suitable substitute for the standard resin-stabilized polyester batting in applications which require laundering because:

(1) The experimental material in quilted and unquilted form with or without a nonwoven scrim does not retain its thermal resistance properties upon laundering and does not exhibit dimensional stability comparable to the standard quilted polyester composite.

(2) The increased thermal resistance values subsequent to laundering which can be achieved with experimental material of higher areal densities results in increased bulk, cost, and overall end-item weight and, therefore, is not a viable option.

Other conclusions resulting from this investigation are as follows:

1. **Materials**

Thermal insulative testing of individual materials indicate:

a. The thermal resistance (insulation value) of both the experimental and the standard polyester batting is not a linear function of batting thickness or areal density. This is primarily because resistance to transmission of thermal radiation is not directly proportional to thickness.

b. As greater bulk density polyester batting is employed, the thermal insulative efficiency on a weight basis (clo/oz/yd^2) decreases, but on a thickness basis (clo/in) increases.

c. As greater bulk density experimental batting is employed, the thermal insulative efficiency on a weight basis (clo/oz/yd^2) decreases, but on a thickness basis (clo/in) remains unchanged.

d. The experimental batting (in the uncompressed state) provides equal thermal insulative protection at approximately one-half the thickness of a polyester batt of equivalent weight (areal density).

e. Compression loading drastically reduces the thickness and corresponding thermal resistance values of both the standard and experimental battings. However, as batt thickness is reduced by compression, the corresponding thermal resistance values do not decrease proportionately. This is attributed to the increasing material bulk density, which induces changes in the proportion and rate of radiative, convective and conductive heat energy transfer.

2. Composite Liners

Comparative evaluation of standard and candidate liner composites show:

a. The thermal insulative values of composites can be estimated with reasonable accuracy using thermal performance data of the component materials. However, quilting or the use of cover fabric on insulating materials with relatively high radiative losses can result in errors in excess of 20%.

b. The uncompressed polyester batting's insulative value is significantly increased by the addition of nylon ripstop cover fabrics, whereas the insulative value of the denser, opaque experimental batting remains approximately the same. This indicates a reduction in convective and radiative thermal losses through the comparatively translucent polyester batt. Thus, although the unquilted experimental batting liner composite was projected to provide equal thermal insulative protection at half the bulk of an equivalent weight unquilted polyester batting liner composite, its actual R value was found to be 24% less than the unquilted polyester batting liner composite.

c. Although quilting reduces the loft and the thermal insulative value of the polyester batting composite, it is required to retain the dimensional and thermal insulative properties if the composite is to be subjected to military laundering. Since the Army's standard polyester batting liner composite is subjected to military laundering, it must be fabricated in the quilted form.

d. In comparing the standard quilted polyester batting and the unquilted experimental batting composite of equivalent weight and thickness, the experimental composite displayed an initial 15% higher thermal resistance value. However, upon laundering, a 14.6% decrease in the experimental composite's thermal resistance value coupled with a 4.2% increase in the quilted standard thermal resistance value eradicated the initial experimental composite's thermal insulative performance advantage. Furthermore, the unquilted experimental composite shrunk 13.4% in surface area while the quilted standard's loss in surface area was a minimal 4.2%.

e. Comparable thermal protection with minimal shrinkage upon laundering was attained both with an unquilted experimental batting sandwiched between nonwoven polyester scrim and a quilted heavier weight experimental batting liner composite. Both are of greater weight and bulk than the standard quilted polyester liner composite.

VII. RECOMMENDATIONS

The thermal resistance properties of the experimental insulating material are sufficiently promising to warrant further study in applications where laundering is not required.

LIST OF REFERENCES

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